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The Plains CO_2 Reduction (PCOR) Partnership: developing CO_2 sequestration opportunities for the central interior of North America

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Abstract

The Plains CO_2 (PCOR) Reduction Partnership is demonstrating the efficacy of CO_2 sequestration in the central interior of North America through regional characterization and multiple validation and demonstration activities. Four CO_2 sequestration field validation tests are at various stages of implementation: three that will store CO_2 in the deep subsurface and one that will store carbon in the near-surface soils and sediments of wetlands and associated grasslands. The PCOR Partnership is initiating two demonstration projects focusing on full-scale injection of CO_2 into deep saline geologic formations for CO_2 sequestration. Public outreach is addressed in part through the creation of several 30-minute documentaries.

Keywords: CO_2; sequestration; PCOR Partnership; carbon capture and storage (CCS); DOE regional partnerships; enhanced oil recovery

1. Introduction

Established in 2003, the Plains CO^2 Reduction (PCOR) Partnership is one of seven U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) Regional Carbon Sequestration Partnerships (RCSPs). The PCOR Partnership region includes all or part of nine states (Iowa, Minnesota, Missouri, Montana, Nebraska, North Dakota, South Dakota, Wisconsin, and Wyoming) and four Canadian provinces (Alberta, British Columbia, Manitoba, and Saskatchewan) and is managed by the Energy & Environmental Research Center (EERC) at the University of North Dakota (UND) in Grand Forks, North Dakota.

Current activities of the partnership include four field validation tests, two commercial-scale CO^2 sequestration demonstrations (Figure 1), along with regional characterization, regulatory and permitting activities, and public

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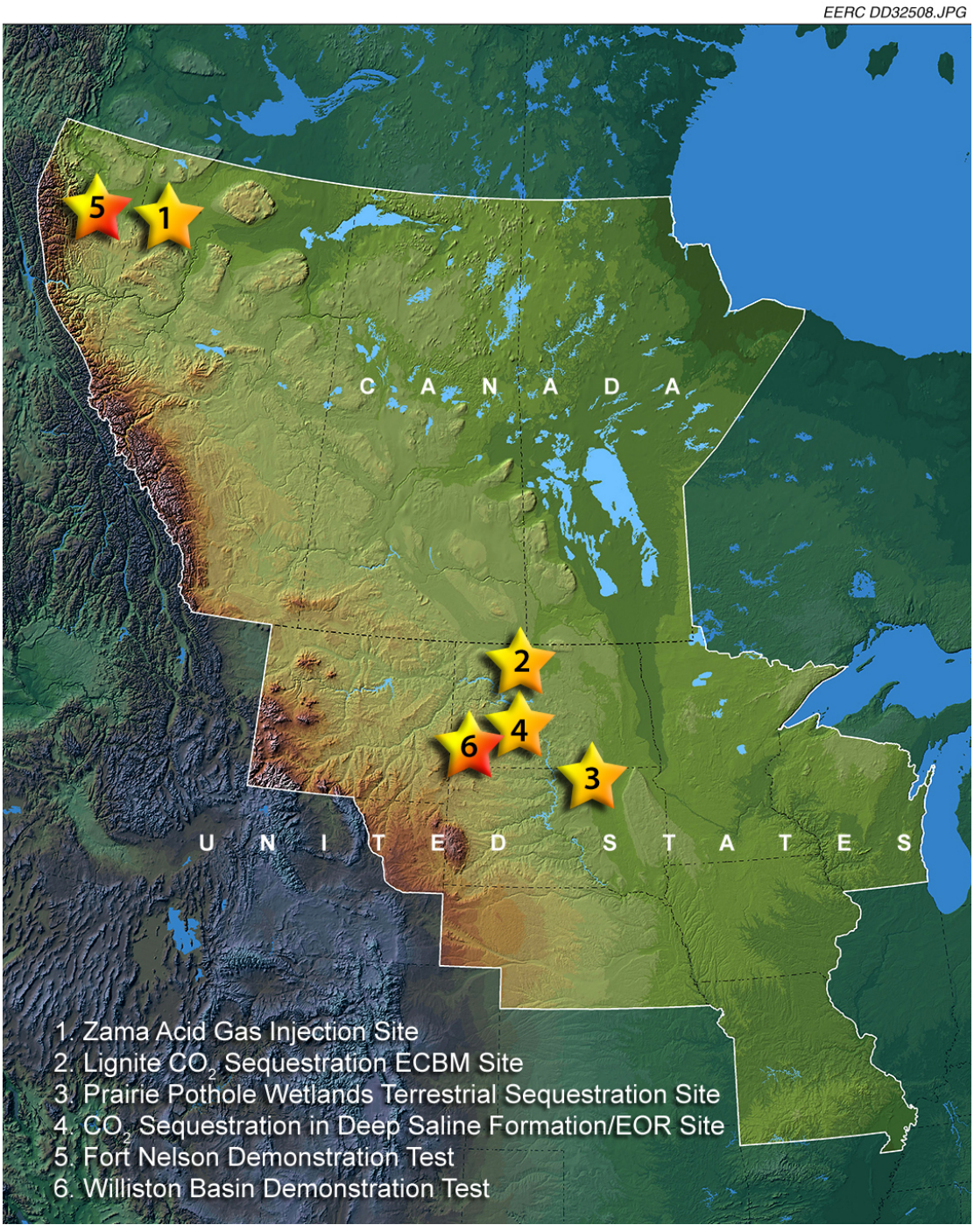

Figure 1. PCOR Partnership validation test sites and demonstration test sites.

outreach. The goal of the PCOR Partnership is to demonstrate the efficacy of CO_2 sequestration in the central interior of North America.

2. Results – regional characterization

The goal of the PCOR Partnership regional characterization effort is to characterize the PCOR Partnership region with respect to regional sequestration opportunities and to communicate this information through our Web-based Decision Support System (DSS, © 2007 EERC Foundation). The PCOR Partnership DSS has been designed to facilitate the assessment of potential CO_2 sequestration projects in the region.

Crucial aspects to the regional characterization efforts include 1) identifying CO_2 sequestration technologies and approaches suitable and available for large-scale deployment in the PCOR Partnership region; 2) maintaining a current database of major stationary CO_2 sources; 3) continuing to derive CO_2 capacity estimates for a variety of geologic sink scenarios; and 4) accurately estimating the costs of capture, compression, and transportation.

Characterization of the region's sinks and major stationary CO_2 sources is proceeding systematically in collaboration with state and/or provincial geologic surveys and numerous other partners. The major geologic sink types being characterized include oil and gas reservoirs with tertiary enhanced oil recovery (EOR) potential, depleted oil and gas reservoirs, deep saline formations, and unminable coal seams.

Figure 2 illustrates the distribution of the major stationary CO^2 sources and the major sedimentary basins that contain geologic strata (sinks) most suitable for sequestration targets. The geographic juxtaposition of the geologic

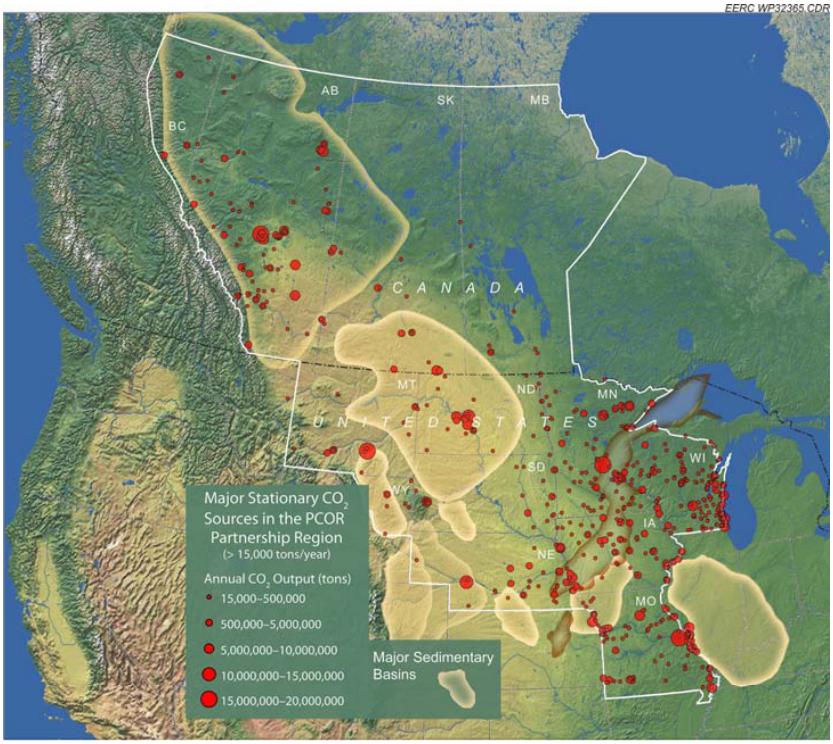

Figure 2. Distribution of major stationary CO_2 sources and sedimentary basins in the PCOR Partnership region.

sinks and sources provides insight into the most likely opportunities for CO_2 sequestration projects in the region and is the foundation for the development of a regional vision for carbon management.

3. Results – field validation tests

Through the fall of 2009, the PCOR Partnership will be developing and conducting four CO_2 sequestration field validation tests: three that will store CO_2 in the deep subsurface and one that will store carbon in the near-surface soils and sediments of wetlands and grasslands. These field projects are designed to develop the expertise, real-world experience, and business models needed to implement major, full-scale, long-term CO_2 sequestration projects in the region.

3.1. Zama Field validation test

The goal of the field validation test in the Zama Field of Alberta is to evaluate the potential for geological sequestration of CO_2 as part of a gas stream that also includes high concentrations of H_2S. This acid gas mixture is being injected for the concurrent purposes of CO_2 sequestration, H_2S disposal, and EOR. A pinnacle reef structure at a depth of 1600 meters below the surface is the target for injection. The geometry of the structure is analogous to an upside down cup reaching a vertical height of approximately 120 meters and covering an area of about 16 hectares. The injection zone is encased in anhydrite that is greater than 90 meters thick at the site and provides a significant seal for the injection operation.

Injection operations at the location began in December 2006 and have continued relatively uninterrupted (aside from routine maintenance and production well workovers) through the time of this report. The reservoir has accepted over 18,000 tonnes of acid gas to date with an average composition of 76% CO_2 and 24% H_2S. A brief period of oil production occurred in July 2008 following over 18 months of water production but was not sustained, likely due to the fractured nature of this carbonate system. In an attempt to regain production, perforations in the target injection zone have been shifted closer to the middle of the reservoir, and a new production well is being considered at the location.

In an effort to prove the long-term efficacy for CO_2 sequestration through EOR using acid gas, the PCOR Partnership, in conjunction with Apache Canada, Ltd., initiated a monitoring, mitigation, and verification (MMV) program for the site based on the following philosophy:

1. The use of existing datasets should be maximized in an effort to characterize the baseline conditions of the site.
2. The use of invasive or disruptive technologies to acquire new data will be minimized.
3. MMV data acquisitions will be coordinated with routinely scheduled operation activities.
4. The monitoring operations will be as transparent as possible to the day-to-day field operations.

This is being accomplished through the use of a multidisciplinary team assembled to determine and prove the long-term containment of the injectate. Program elements include the evaluation of the geomechanical, hydrogeological, and geochemical regimes associated with the subsurface as well as a robust evaluation of the engineering processes involved in operating an active oil field. The activities at Zama are providing insight regarding sink integrity (i.e., seal degradation), hydrogeological flow regimes, geochemical reactions, and geomechanical properties of this system.

Results of geomechanical evaluations show the cap rock is competent and will withstand injection pressures above that of the permitted threshold. Hydrogeological investigations regarding fluid flow and stratigraphic containment indicate that hundreds of thousands of years would be required for migration of fluids from the immediate area. A perfluorocarbon gas tracer has been injected into the reservoir to aid in the detection of any leakage out of the pinnacle into adjacent stratigraphic horizons. Fluid samples will be analyzed to detect this tracer

and positively determine whether any leakage is occurring. A thorough investigation of the Zama Field with respect to wellbore leakage was conducted and lends confidence to the understanding of the field as a sequestration container. As expected from a field that has been in operation for more than 40 years, wellbores as potential leakage pathways may necessitate attention during large-scale operations, but the current demonstration site's wellbores appear to have a solid bond throughout the stratigraphic section. Ongoing geochemical evaluations at the site will provide insight regarding the long-term fate with regard to trapping mechanisms in this environment.

Through these activities, confidence in the ability of the Zama oil field to provide long-term containment of injectate will be achieved. While this project has been focused on one of the hundreds of pinnacles that exist in the Zama Field, many of the results obtained can be applied not only to additional pinnacles in the Alberta Basin, but to similar structures globally.

3.2. Lignite field validation test

The PCOR Partnership lignite field validation test is investigating the ability of unminable lignite seams to act as sinks for CO_2 during simultaneous CO_2 sequestration and enhanced coalbed methane (ECBM) production.

In August 2007, five wells were drilled on the Burke County, North Dakota, test site. Geophysical information on the properties of the subsurface system was collected. The analysis of the data collected confirmed that the targeted coal seam has sufficient thickness to provide enough storage capacity to conduct a relevant CO_2 injection test. The target coal seam is overlain and underlain by relatively impermeable rocks that will prevent vertical migration of the injected CO_2, thereby confining it to the zone of injection. Additionally, gas samples and approximately 9 meters of rock and coal core samples, three of which were from the primary coal seam of interest, were retrieved from the anticipated injection well.

Well development activities are continuing in order to prepare for CO_2 injection and subsequent monitoring and data collection. Stochastic simulation, deterministic estimation, and geostatistical methods have been employed to populate a subsurface geologic model with structural, physical, and chemical properties. This model will be used to estimate reservoir capacity with respect to its CO_2 sequestration potential.

3.3. Williston Basin field validation test

The goal of the Williston Basin field validation test is to evaluate the potential for geological sequestration of CO_2 in a deep carbonate oil reservoir for the dual purpose of CO_2 sequestration and EOR. While injection and monitoring of large volumes of CO_2 have been conducted in a carbonate reservoir at Weyburn, Saskatchewan, it is anticipated that the depth of the North Dakota project will be nearly twice that of the Weyburn project. The results of the project will yield previously unavailable insight regarding the effects of high pressure and temperature conditions encountered at depths of 3000 meters or more on several aspects of geological sequestration, including geochemical, geomechanical, monitoring, and operational parameters. The plan is to target a geologically similar reservoir for our commercial-scale Williston Basin demonstration so that the results of this test provide a critical foundation for those activities.

A group of oil fields in the vicinity of Dickinson, North Dakota, has been identified as being the primary potential sites for injection and EOR operations. Geological and hydrogeological investigations of those potential fields are under way. Key data sets including well logs, drill stem test results, core analyses, and injectivity data have been acquired for hundreds of wells in the Dickinson area and entered into a commercial geological modeling software package. These data sets are being used to characterize the geological setting of the study area at the reservoir, field, and subregional scales. Maps of key properties for injection target formations and seals (e.g., depth to top, total thickness, porosity, porosity–thickness, and salinity) have been created. These maps have been combined geostatistically with other data elements to develop subregional petrophysical models of the study area in

southwestern North Dakota. The results indicate that 1) there are several oil reservoirs in at least three carbonate formations (the Ordovician Red River Formation, the Mississippian Lodgepole Formation, and the Mississippian Mission Canyon Formation) in the Dickinson area that may be suitable candidates for CO_2-based EOR and sequestration and 2) each potential injection formation is overlain by thick, competent seals, with the entire region being overlain by a minimum of 300 m of Cretaceous shales (Colorado Group and Pierre Formations).

In addition to the characterization of the study area, laboratory efforts designed to examine the effects that CO_2 injection at reservoir conditions can have on the rocks of the potential injection formations and seals have been initiated. The experiments are focused on examining the effects of high-pressure and -temperature CO_2 on the porosity, permeability, geochemistry, and geomechanical integrity of the carbonates, shales, and anhydrites that make up the sinks and seals in the Dickinson area. The emphasis of initial experiments under this program is focused on developing data on the rates of reaction with respect to dissolution and precipitation of various minerals. These types of data are critical to developing accurate predictions with respect to key operational aspects such as injectivity and migration within the reservoir and longer-term aspects such as plume transport and fate. The PCOR Partnership considers the experiments in question to be directly applicable to key operational considerations, such as seal integrity and injectivity.

3.4. Prairie pothole terrestrial field validation test

The goal of the prairie pothole terrestrial field validation test is to develop the technical capacity to systematically identify, develop, and apply alternate land-use management practices to the prairie pothole ecosystem (at both local and regional scale) that will result in greenhouse gas reductions and salable carbon offsets for our partner, Ducks Unlimited Inc. Progress has been made toward Voluntary Carbon Standard (VCS) and International Standard Organization (ISO) recognition of carbon offsets from native prairie preservation. An initial grassland project gap analysis was performed in 2008 by an independent third-party verifier to document project attributes that require further attention or correction before earning final VCS and ISO approval. Carbon unit features are now able to connect to the central projects database. The purpose of this database development procedure is to facilitate carbon project data maintenance and reporting which are requirements for carbon credits transacted in the voluntary or regulatory market. Carbon credit buyers need the ability to trace the purchase of their credits to unique parcels for project validation purposes.

Sampling efforts continue throughout the PCOR Partnership region; soils have been collected from various vintages of grasslands in Montana, North and South Dakota, Minnesota, and Iowa, and gas flux data are collected biweekly from a series of wetland catchments in South Dakota. These data have been instrumental in advancing terrestrial carbon credits in the marketplace.

Several models are being developed to assist in carbon easement acquisition. An economic model is being constructed to examine land units affected by various wetland restoration actions. This model, along with another that will predict the probability that a parcel of land will remain in a particular land use (with varying commodity prices and subsidy and conservation payments), will be used in a “price-point” and/or “willingness to sell/convert” analysis on private lands in the PCOR Partnership region.

4. Results – demonstration projects

Whereas the field validation tests are focusing on validating technologies and identifying locations in the PCOR Partnership region that can support future full-scale geological and terrestrial sequestration opportunities, the most recent phase of the PCOR Partnership is initiating two demonstration projects that focus on full-scale injection of CO_2 into deep saline geologic formations for CO_2 sequestration. The first demonstration will inject CO_2 into saline formations in the Williston Basin for the dual purpose of sequestration and EOR. The second demonstration

involves MMV support for the injection of CO_2 captured from one of the largest gas-processing plants in North America into a saline formation in northeastern British Columbia, Canada.

4.1. Williston Basin demonstration project

The Williston Basin demonstration will include injection for CO_2 sequestration and EOR in select oil fields in the Williston Basin. The primary objectives of this activity are 1) to gather characterization data that will verify the ability of the target formations to store CO_2, verifying capacity estimates that indicate that 50% of the region's point-source CO_2 emissions over the next 100 years could be stored in depleted regional oil fields; 2) to develop North America's infrastructure in order to transport CO_2 from the source to the injection site; 3) to advance the regulatory and permitting framework in North America; 4) to provide a test bed for developing technologies related to sequestration of anthropogenic CO_2; and 5) to develop a mechanism by which carbon credits can be monetized for CO_2 sequestered in geologic formations.

The Williston Basin project will transport a minimum of 500,000 tons a year of CO_2 from the Basin Electric Power Cooperative's Antelope Valley Station, an existing conventional coal-fired power plant in central North Dakota. The power plant will be retrofitted with a system that can capture CO_2 from its flue gas stream. The CO_2 will then be compressed and transported in a supercritical state via pipeline to the target injection location (see Figure 4).

Several R&D (research and development) issues will be addressed during the Williston Basin demonstration. R&D activities will be specifically focused on predictive modeling, capture, injection, and monitoring operations to demonstrate that large-scale sequestration of CO_2 into oil fields is a viable strategy for sequestering significant amounts of CO_2 emissions from the PCOR Partnership region.

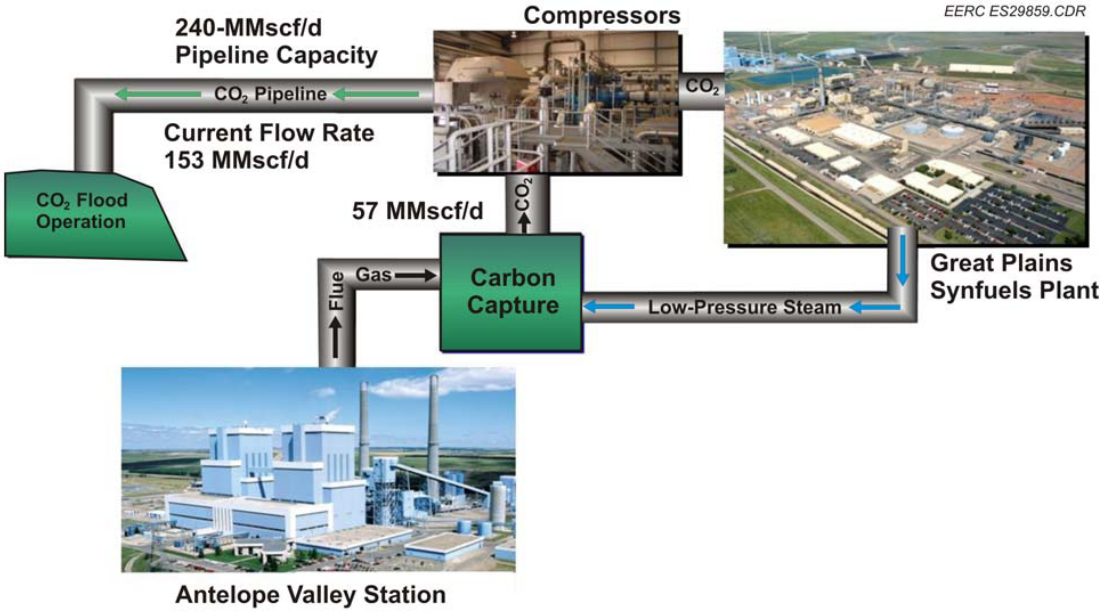

Figure 4. Basin Electric Power Cooperative CO_2 optimization project.

4.2. Fort Nelson demonstration project

The demonstration project near Fort Nelson in northeastern British Columbia, Canada, will involve the design and implementation of a MMV program associated with an effort to inject over 1 million tons of CO_2 a year into a brine formation. Key partners with the EERC in this international project will be Spectra Energy; Natural Resources Canada; and the British Columbia Ministry of Energy, Mines, and Petroleum Resources.

R&D issues that will be addressed during the Fort Nelson brine formation demonstration will be focused on predictive modeling, monitoring, and injection operations, but in this case to demonstrate that large-scale sequestration of CO_2 into a brine formation is also a safe and permanent solution for storing significant amounts of CO_2 emissions from the PCOR Partnership region.

5. Results – outreach

The PCOR Partnership Program has a specific public outreach and education effort that is focused on providing key materials that raise public awareness of sequestration concepts and opportunities in the region and provide stakeholders with information about sequestration activities in the region. To meet the goals of this activity, the PCOR Partnership outreach efforts are focused in three major media products: 1) broadcast documentaries developed in cooperation with Prairie Public Broadcasting; 2) a public Web site; and 3) various reports, fact sheets, and a regional atlas that convey PCOR Partnership activities and other topics relevant to CO_2 sequestration. To date, three 30-minute documentaries have been completed and aired: Nature in the Balance: CO_2 Sequestration, Reducing Our Carbon Footprint: The Role of Markets, and Out of the Air – Into the Soil: Land Practices That Reduce Atmospheric Carbon Levels.

6. Conclusions/regional vision

The PCOR Partnership is a diverse group of public and private sector stakeholders working together to better understand the technical and economic feasibility of capturing and storing CO_2 emissions from stationary sources of CO_2 in the central interior of North America. Over the past 5 years since its inception, the PCOR Partnership has assessed and prioritized the opportunities for sequestration in the region and helped to resolve the technical, regulatory, and environmental barriers to the most promising sequestration opportunities. At the same time, the PCOR Partnership has informed policy makers and the public regarding CO_2 emission sources, sequestration strategies, and sequestration opportunities. The results of the first 5 years of effort in the PCOR Partnership have also developed the data sets and information needed to develop a regional vision for carbon management.

The PCOR Partnership is working to achieve this regional vision with respect to CO_2 sequestration that draws on the existing regulatory framework, expertise, and economic drivers of the region's industries. Judicious site selection, the establishment of geologic sequestration units, and the implementation of practical cost-effective MMV strategies are all key elements to making this regional vision a reality. In this vision, the EOR opportunities would be exploited first, followed by nonresource recovery-related sequestration in the future. At present, the region's demand for CO_2 for EOR applications outstrips the current supply. The PCOR Partnership region is poised to play a major role in the establishment of CCS as a commercial technology because of a combination of favorable geology and socioeconomic conditions.